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(54) IMPROVEMENTS IN OR RELATING TO FIELD—EFFECT TRANSISTORS

(71) We, SIEMENS AKTIENGESELLSCHAFT, a German Company of Berlin and Munich, German Federal Republic, do hereby declare the invention, for which we

pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

The present invention relates to n-channel insulating layer field-effect transistors.

Integrated circuits provided with MIS-transistors are currently frequently constructed in epitaxial layers arranged on an insulating substrate. For this purpose, an epitaxial silicon layer is deposited on a monocrystalline insulating substrated, e.g. of sapphire or spinel. Doped zones are then produced in this epitaxial silicon layer in accordance with the particular type of semiconductor component to be produced. A disadvantage of this technique is that, as a result of lattice variations between the substrate and the epitaxial layer positively charged surface states occur which induce an n-conducting zone in the epitaxial silicon layer in the vicinity of the substrate surface. This n-conducting zone has a thickness equal to a Debye-length and is thus about 5 nm thick. An n-conducting zone of this type at the substrate surface has a disadvantageous effect on the electrical behaviour of a field-effect transistor, for example, which consists of n^+-conducting source and drain zones and an interlying n-conducting channel zone, since this induced n-conducting zone forms a further disturbing channel between the source and the drain which leads to a high blocking current for the field-effect transistor (see Appl. Phys. Letters *11*, (1967), pages 132 to 134). This blocking current can be suppressed by introducing dopant into the induced zone of the epitaxial silicon layer by ion implantation, so as to reduce the conductivity of the induced zone. The concentration of the boundary surface states which produce the induced zone fluctuates very considerably, however. The implantation doping used for compensation purposes must therefore be such that it serves to compensate for the effect of even the greatest possible concentration of boundary surface states. The strength of the implantation doping required is then, however, already such that the gradient of the field-effect transistor characteristic is considerably reduced.

It is an object of the present invention to provide an insulating field-effect transistor constructed in an epitaxial silicon layer on an insulating substrate and which has a low blocking current and a high transistor characteristic gradient.

According to the invention, there is provided an n-channel insulating layer field-effect transistor comprising an n-doped source zone, an n-doped drain zone and a weakly doped p-doped channel zone formed in an epitaxial silicon layer on an insulating substrate, wherein a strongly p-doped zone containing implanted p-dopant is located in said epitaxial layer in contact with the surface of said substrate, within a portion of the epitaxial layer adjacent to said source zone, a part of the concentration maximum of implanted dopant ions in said p-doped zone being located at a distance from the substrate surface which is a multiple of the Debye-length in said channel zone, said p-doped zone acting to interrupt any interference channel present in said epitaxial layer adjacent to the substrate boundary so as to electrically separate said source zone therefrom by a p-n boundary layer.

The invention is based on the realisation that, in order to reduce the blocking current produced by the boundary surface states, it is sufficient to interrupt the conductive interference channel which is induced by these states and which is present at the substrate surface, so that a conductive

connection is no longer established between the source and the drain via this interference channel, and that it is unnecessary to compensate by implantation for the entire n-conducting zone induced by the boundary surface states.

In accordance with the invention therefore, the zone of the epitaxial silicon layer which is provided with implanted dopant particles does not extend over the entire surface used for the insulating layer field-effect transistor as in previously known techniques, but is limited to a portion of the epitaxial silicon layer which includes the source zone. In the transistor according to the invention, the interference channel is interrupted by ensuring that the concentration of the implanted dopant ions in the implanted zone is such that a p-n boundary layer is present between this implanted zone and the n-conducting interference channel. This p-n boundary layer forms an electrical barrier by means of which the n-conducting interference channel which was originally produced as a result of boundary surface states and which is present adjacent the substrate surface is now interrupted. The implanted zone can underly and extend laterally of the source zone, or it can be of annular shape and surround the source zone, In a MOS-transistor which is constructed in an insular semiconductor layer, it is sufficient if the implanted zone lies adjacent to but spaced from the source zone and extends to both opposite ends of the island, and thus cuts off the source zone from the interference channel. The known insulating layer field-effect transistor can be regarded as a transistor which, in addition to the gate electrode arranged on the insulating layer, possesses a further "gate electrode" constituted by the surface of the insulating substrate which is provided with the boundary surface states. In the known field-effect transistor, the implantation doping which extends over the entire epitaxial layer virtually switches the additional "gate electrode" to zero potential, and consequently reduces the gradient of the characteristic of the field-effect transistor. In comparison, in a field-effect transistor in accordance with the invention, the gradient of this field-effect transistor is not fundamentally affected by the implantation doping.

In a preferred embodiment of the transistor of the invention, in the implanted doped zone, the concentration maximum of the implanted ions lies within a distance of 100 nm from the substrate surface. Preferably, the concentration of the implanted dopant ions in this region is between 2×10^{16} and 2×10^{17} ions per cm^3.

The transistor of the invention can advantageously be prepared by selectively doping to form the doped zone by means of ion implantation carried out not over the whole of the semiconductor regions of the insulating layer field-effect transistor, but merely in that region including the source zone and a part of the channel on the source side. The implantation doping is effected through a mask which leaves uncovered that part of the field-effect transistor which is to be implanted, i.e. the source zone and a part of the channel zone adjacent thereto. The mask may consist, for example, of a photolacquer. The implantation doping is carried out with an ion energy such that the distribution maximum of the implanted dopant ions lies immediately above the boundary surface between the silicon layer and the insulating substrate.

The invention will now be further described with reference to the drawing, in which:-

Figure 1 is a schematic side-sectional view of one embodiment of the invention;

Figure 2 is a schematic side-sectional view of a second embodiment of the invention; and

Figure 3 is a similar view to that of Figure 1, to illustrate the production of the field-effect transistor of Figure 1.

Referring to Figure 1, on a monocrystalline substrate 1, which consists of sapphire (Al_2O_3), there is arranged an epitaxial silicon layer 2 which is doped to be p-conducting with a basic doping of $10^{14} - 5 \times 10^{15}$ per cm^3. In this epitaxial silicon layer, there are arranged a highly n-doped drain zone 3 and a likewise highly doped source zone 4. The channel zone 5 between them has the original doping of the layer 2. At the boundary surface 6 between the insulating substrate 1 and the epitaxial silicon layer 2, the insulating substrate contains boundary surface states 7 which are positively charged. These positive states 7 induce an interference channel 8 in the layer 2 adjacent the boundary surface 6 which contains conductivity electrons and thus is n-conductive. The source zone 4 and that part of the channel zone 5 which adjoins the source zone is crossed adjacent the boundary surface 6 by a zone 9 which contains implanted dopant ions, e.g. boron ions. This zone 9 does not extend as far as the drain zone 3 but is limited to a region 21 which underlies and extends laterally of the source zone 4. This region 21 extends no further than about m beyond the lateral boundaries of the source zone. The dopant concentration of the zone 9 is sufficiently high for it to be strongly p-doped. The concentration maximum of the implanted ions runs along a line 10 a part of which lies parallel to and at a distance of about 100 nm from the substrate surface 6. The zone 9 is electrically isolated by the boundary layer of a p-n junction 11 both from the remaining part of the surface zone

4 and from the n-conducting interference channel 8. The result of this is that the source zone 4 is no longer conductively connected to the interference channel 8, since the interference channel is cut by the p-n junction 11. At the surface of the epitaxial silicon layer, an insulating layer 12 consisting of silicon dioxide is arranged above the channel zone 5 and on this an aluminium layer is arranged as a gate electrode 13 above the channel zone 5. The insulating layer 12 contains windows through which conductor paths 14 and 15 lead to the source zone 4 and the drain zone 3 respectively and thus form electric contacts therewith.

In the embodiment illustrated in Figure 2, the field-effect transistor is formed in an island of weakly p-doped semiconductor material produced by etching from the epitaxial layer 2. The n^+-doped source zone 4 and drain zone 3 are formed at opposite sides of the island. The induced n-doped interference channel 8 adjacent the substrate 1 is interrupted by a p-doped zone 9 which, in this example lies adjacent to but spaced from the source zone 4, and extends to both ends of the island.

The production of the transistor in accordance with the invention shown in Figure 1 is schematically illustrated in Figure 3. A weakly p-doped silicon layer 2 is first deposited epitaxially onto an insulating substrate which in the example under consideration consists of sapphire. Individual islands may, if desired, be etched out of this layer as in the embodiment of Figure 2. In the epitaxial silicon layer 2, a highly n-doped source zone 4 and drain zone 3 are produced, e.g. by diffusing-in phosphorus. The epitaxial silicon layer 2 is then covered by an electrically insulating layer 12 which may consist, for example, of silicon dioxide or of silicon nitride. A photolacquer layer 20 is then deposited onto this insulating layer 12. The photolacquer layer 20 is then exposed through a photo-mask and developed to form a window 31 in the photolacquer layer; this window is located above the source zone 4 but has an area which is larger than that of the source zone. Implantation of p-dopant ions 22, e.g. boron ions, is then carried out, the photolacquer layer 20 serving as an implantation mask. The energy of the ions 22 used is such that in the epitaxial silicon layer 2, the concentration maximum of the implanted ions runs along a line 10, a part of which lies parallel to and at a distance of about 0.1 μm from the surface 6 of the insulating substrate, which is a multiple of the Debye length in channel zone 5. The implantation is carried out with an overall dosage of from 2×10^{12} to 5×10^{12} per cm^3. Subsequently, the photolacquer 20 is removed and windows are etched into the insulating layer 12 for the subsequent application of the source and drain contacts 14 and 15 respectively, and these contacts and the gate electrode 13 are formed by vapour deposition through a mask.

WHAT WE CLAIM IS:-

1. An n-channel insulating layer field-effect transistor comprising an n-doped source zone, an n-dope drain zone and a weakly p-doped channel zone formed in an epitaxial silicon layer on an insulating substrate, wherein a strongly p-doped zone containing implanted p-dopant is located in said epitaxial layer in contact with the surface of said substrate, within a portion of the epitaxial layer adjacent to said source zone, a part of the concentration maximum of implanted dopant ions in said p-doped zone being located at a distance from the substrate surface which is a multiple of the Debye-length in said channel zone, said p-doped zone acting to interrupt any interference channel present in said epitaxial layer adjacent to the substrate boundary so as to electrically separate said source zone therefrom by a p-n boundary layer.

2. A field-effect transistor as claimed in Claim 1, wherein said p-doped zone extends laterally of said source zone.

3. A field-effect transistor as claimed in Claim 2, wherein said p-doped zone extends laterally of said source zone by at most 5μm.

4. A field-effect transistor as claimed in any one of Claims 1 to 3, wherein the concentration maximum of the implanted dopant ions in said p-doped zone lies at a distance of at most 0.2 μm from the substrate surface; and wherein the maximum concentration of said dopant ions is at least $5 \times 10^{16}/cm^{-3}$.

5. An n-channel insulating layer field-effect transistor substantially as hereinbefore described with reference to and as shown in Figure 1 or Figure 2 of the drawing.

6. A method of producing a field-effect transistor as claimed in Claim 1, comprising the steps of depositing a p-conducting epitaxial silicon layer on an insulating substrate, producing an n^+-doped source zone and an N^+-doped drain zone in said silicon layer, implanting p-dopant ions in said epitaxial silicon layer within a region which underlies said source zone and extends laterally of said source zone by not more than 5 μm, implantation being effected through a mask so that no p-dopant ions are implanted in the remainder of said silicon layer.

7. A method as claimed in Claim 6, wherein the energy of the implanted dopant ions is such that the concentration maximum of the implanted dopant ions is situated at a distance of about 0.2μm from the substrate surface.

8. A method as claimed in Claim 4 or Claim 5, wherein the maximum concentra-

tion of the implanted dopant ions is from 2 x 10^{16} to 2 x $10^{17}/cm^{-3}$.

9. A method of producing a field-effect transistor as claimed in Claim 1, substantially as hereinbefore described with reference to Figure 3 of the drawing.

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Fig.1

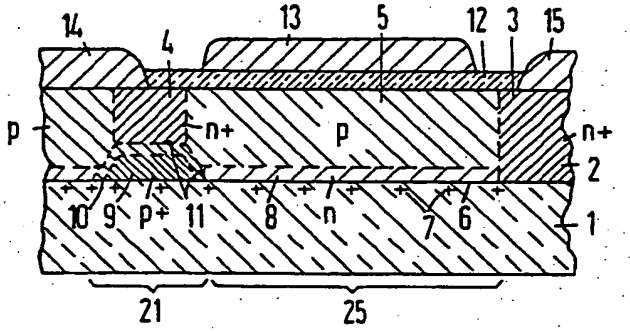

Fig.2

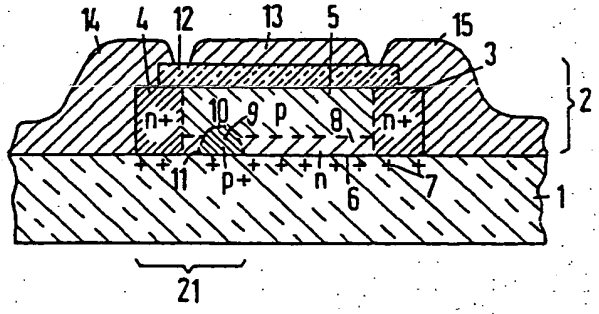

Fig. 3